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6. AUTHOR(S)
John C. Foster and Frank D. Lind

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Massachussetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139-4307

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13. ABSTRACT *(Maximum 200 Words)*

This is a final report for the MIT Haystack Observatory ISIS Array DURIP award. The ISIS Array (Intercepted Signals for Ionospheric Science) is an instrumentation network funded by the DoD DURIP program. This project is constructing a coherent software radio network capable of operating as a flexible multi-role distributed radio science instrument. ISIS hardware purchasing is complete and all components have been delivered. A complete inventory of the ISIS purchasing and cost breakdown is attached at the end of this report. We have purchased hardware for seven nodes each of which will be contained in a ruggedized transport rack. Assembly of the ISIS nodes is well underway with the first two nodes being fully completed including software configuration. The additional five are in various stages of assembly. It is expected that assembly and software configuration of all the nodes will be complete by the end of August 2005. By late summer 2006 DURIP funded nodes are likely to be deployed at Cornell, Sienna College (Albany), Dartmouth, UNH, Greenbank, UW, and Manastash Ridge (with equivalent equipment at Millstone). The ISIS Array was recently (June 2005) the subject of a workshop hosted at Haystack Observatory to discuss the array and collaborations in distributed radio science instrumentation among selected university partners.

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DURIP: Intercepted Signals for Ionospheric Science (ISIS) Instrumentation for a Small Radio Science Array

Principal Investigator:	Dr. John C. Foster Associate Director Haystack Observatory
Telephone:	(781) 981-5621
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AFOSR Technical Oficer:	David L. Byers, Ph. D.

John C. Foster
Principal Investigator

Frank D. Lind
Co-Principal Investigator

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DURIP : Intercepted Signals for Ionospheric Science
Final Report
John C. Foster and Frank D. Lind
MIT Haystack Observatory
July 27, 2005

This is a final report for the MIT Haystack Observatory ISIS Array DURIP award. The ISIS Array (Intercepted Signals for Ionospheric Science) is an instrumentation network currently funded by the DoD DURIP program. This project is constructing a coherent software radio network capable of operating as a flexible multi-role distributed radio science instrument. In particular operational modes involving active and passive multistatic radar imaging, satellite beacon observations of TEC and scintillation, and radio intercept and TDOA applications will be supported over a wide range of operating frequencies (about 0.5 to 500 MHz initially and then up to 2000 MHz with a tuner we will implement). The system is being constructed as a series of ISIS Array Nodes which can coherently capture wide bandwidths of RF signals from a variety of antennas. The array will be capable of applying high performance supercomputing using a grid computing architecture to the real time and batch processing requirements of a variety of experiments. Different operational modes may require the array to be configured with different antennas, however the underlying software radar technology will allow a unified data management, signal processing, and control system. The system will also be used to evaluate a wide variety of configurations and techniques for applications involving scientific and defense applications of intercepted signals. Distributed coherent radio arrays are a fundamentally new technology that has been enabled by the wide availability of GPS signals for synchronization and the development of high bandwidth internet technology which allows voltage level RF data to be delivered from the array elements in realtime. High performance signal processing focused supercomputing can be applied to data from the array to allow for the real time monitoring and imaging of ionospheric structures using signals of opportunity.

ISIS hardware purchasing is complete and all components have been delivered. A complete inventory of the ISIS purchasing and cost breakdown is attached at the end of this report. We have purchased hardware for seven nodes each of which will be contained in a ruggedized transport rack. The nodes will have six RF inputs into two Echotek digital receiver cards. These cards can channelize up to four sub channels from each input or burst large bandwidths from a single RF input. The cards will be able to burst capture up to about 42 MHz of RF bandwidth and stream up to about 10 MHz of bandwidth. They have programmable FPGAs for software radio applications (e.g. rapid spectral power monitoring or software based GPS reception). The cards will be synchronized in time and frequency using a high quality L1 GPS system from Zyfer that provides all network time, triggering, and oscillators for the system. We expect to achieve about 100 nsec alignment in data acquisition start and frequency coherence on the order of 1 part in 10E11. We will have two terabytes of storage in each node for capturing the signals and the distributed array of nodes will have a combined computing capacity of about 32 Gigaflops with and additional capability of 250 billion integer multiply accumulates (2 teraops) in the receiver FPGAs available for special purpose applications (e.g. a software GPS receiver for scintillation observations). Antennas are a fairly modest with a combination of discones, log periodics, LF coils, and helical satcom antennas. We can change the antennas used for different experiments. We have also constructed a cluster computing system and combined it with that of the Millstone Incoherent Scatter Radar for signal processing and data analysis. This central computing system has 32 Gigaflop performance and 20 Tbytes of storage and has been fully operational for six months. The computing system is interconnected using a high performance network switch and multiple gigabit ethernet channels per node. Software configuration for this cluster computer is complete and we are using the Sun Grid Engine to provide distributed batch processing. Currently the cluster is being applied to ISR related data analysis and modeling while we prepare the ISIS array for deployment.

Assembly of the ISIS nodes is well underway with the first two nodes being fully completed

including software configuration. The additional five are in various stages of assembly. It is expected that assembly and software configuration of all the nodes will be complete by the end of August 2005. Testing of the nodes will continue into the fall of 2005. The first node is now slated for deployment to the Greenbank Radio Observatory in October 2005. This deployment has been enabled by funding through MIT Lincoln Laboratory to use an ISIS node for bistatic coherent and incoherent scatter observations using the Greenbank 140 foot telescope (http://www.gb.nrao.edu/140foot/140foot.html). We will also deploy a normal complement of ISIS antennas for making passive radar and scintillation observations when the 140 foot system is not available. The Lincoln Laboratory program has funded the development of our RF tuner board and the second prototype in this development process is currently being designed. We expect to have completed the first RF tuner design and implementation by fall of this year.

For fielding the nodes we intend to space them at friendly universities for initial operations. The University of Washington is going to field one in Seattle and the other at Manastash Ridge Observatory (MRO) during fall 2005. They have recently deployed a third receiver for the Manastash Ridge Radar in Spokane Washington and this system has now demonstrated the practical viability of coherent software radio networks. When the ISIS nodes are deployed to MRO and UW they will move the current receivers in those locations to Canada. This will result in a west coast network consisting of five sites and a sixth will be added shortly there after by UW. We will deploy the remaining ISIS nodes in the northeast with several hundred kilometer spacing (plus the equivalent of a node at Millstone via the digital receivers for the ISR and some selectable antenna inputs). By late summer 2006 DURIP funded nodes are likely to be deployed at Cornell, Sienna College (Albany), Dartmouth, UNH, Greenbank, UW, and Manastash Ridge (with equivalent equipment at Millstone). We will occasionally reconfigure things to try new geometries and pursue different science topics.

The ISIS Array was recently (June 2005) the subject of a workshop hosted at Haystack Observatory to discuss the array and collaborations in distributed radio science instrumentation among selected university partners. We had a very good meeting at Haystack which lasted two days. Representatives from Cornell, BU, Dartmouth, Sienna, UNH, and UW attended directly and we had some participants via the Access Grid from Augsburg college in Minneapolis. Our group at MIT/Haystack of course had a good attendance. There was discussion about the ISIS array design, how we would use the system, and what science topics and results would be investigated using the system. Discussion about how we can build collaborations using the ISIS hardware went well and a number of participants are going to be hosting hardware once it is ready to deploy. There was a great deal of interest in using ISIS as a foundation for working towards the eventual deployment of larger arrays of space science instrumentation (DASI). Some good educational outreach discussions took place and many of the participants from smaller colleges (e.g. Alan Weatherwax of Sienna) were very interested in the opportunities for involving students in the deployment and use of the array. Other participants (e.g. John Sahr of UW and Josh Semeter of BU) were quite interested in involving graduate students and in integrating the use of ISIS into radar remote sensing courses at their universities. This interest is being actively encouraged through a proposal by John Holt of MIT Haystack Observatory to the NSF Cyberinfrastructure TEAM program (submitted May 2005). This proposal seeks to support the human resources aspects of the ISIS program as well as to involve students at many of the institutions listed above in the project on an ongoing basis.

People attending the workshop had the chance to see the first two nodes we have assembled and we gave them a demonstration of the software radar system we use for the ISR from which the ISIS architecture is derived. The second day had a lot of discussion about more general radio science collaborations/consortium among the participants. People were very interested and we asked them to think about how use and participation in the ISIS array project could be of benefit to them. There was quite a bit of interest in a radio science summer school one element of which would be ISIS array focused. This would probably come about as part of our larger efforts at Haystack to host summer schools which focus on AMISR and the MADRIGAL database.

Scientifically we intend to use the array to study the Electric fields driving ionospheric irregularities (i.e. coherent scatter) and its relationship to the plasmasphere boundary layer (SAPS region). The wide frequency coverage of the array combined with active and passive radar techniques will let us observe (and image using interferometry)the E-region irregularities at multiple frequencies and scattering geometries simultaneously. This should allow us to explore plasma physics questions related to the k-space distribution of energy in the unstable E-field driven plasma. The array will also have antennas appropriate for the study of scintillation and in particular we have purchased antennas and filters to observe the Air Force satcom satellite beacons that AFRL uses with SCINDA. We will be working to relate this to observations from Anthea Coster's GPS mapping and observations of L-band scintillations. Dr. Coster and Dr. Lind have recently received NSF Aeronomy funding for a three year project to utilize the ISIS Array in conjunction with GPS measurements for the study of ionospheric irregularities in the Plasmasphere Boundary Layer. This project includes some personel and operational support for deploying and using the ISIS array hardware.

For defense related applications we will be able to provide data from the array to appropriate parties and pursue applications of the array with programs whose needs could be served using the ISIS data or ISIS enabled science investigations. Possible applications include monitoring of radar clutter over large regions, the monitoring of scintillations at midlatitudes, multistatic radar observations with an illuminator like Millstone, networked passive radar for aircraft tracking, and signals intelligence applications. One development in this regard is that a similar (single site) system for Aircraft tracking is being constructed by Aaron Lanterman of Georgia Tech. We helped him specify the hardware which has been purchased and the resulting radar will be architecturally compatible with our system.This may lead to future collaborations for applications involving aircraft tracking.